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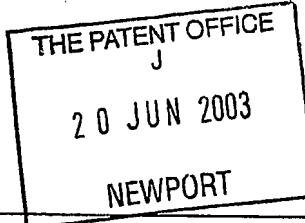
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Dated 5 July 2004

Stephen Hordley

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P021573 GB

2. Patent application number

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0314372.4

20 JUN 2003

3. Full name, address and postcode of the or of each applicant (underline all surnames)

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Patents ADP number (if you know it)

51649002

If the applicant is a corporate body, give the country/state of its incorporation

Virginia, USA

4. Title of the invention

Bearings

5. Name of your agent (if you have one)

Harrison Goddard Foote

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Description 16

Claim(s) 4

Abstract 1

Drawing(s)

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11.

I/We request the grant of a patent on the basis of this application.

Marion Goddard Foot Signature Date
19 June 2003

12. Name and daytime telephone number of person to contact in the United Kingdom

David Goddard

0161 427 7005

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BEARINGS.

5 The present invention relates to plain bearings and particularly, though not exclusively, to plain bearings having a strong backing layer, a layer of a first bearing material on the backing layer and a layer of a second bearing material on the layer of first bearing material.

10

Plain bearings for use as crankshaft journal bearings in internal combustion engines, for example, are usually semi-cylindrical in form and generally have a layered construction. The layered construction frequently 15 comprises a strong backing material such as steel, for example, of a thickness in the region of about 1mm or more; a lining of a first bearing material adhered to the backing and of a thickness generally in the range from 0.1 to 0.5mm; and often a layer of a second bearing 20 material adhered to the surface of the first bearing material and having a thickness of less than about 25 μ m. The surface of the second bearing material forms the actual running surface with a co-operating shaft journal 25 surface. The backing provides strength and resistance to deformation of the bearing shell when it is installed in a main bearing housing or in a connecting rod big end for example. The first bearing material layer provides suitable bearing running properties if the layer of the second bearing material should be worn through for any 30 reason. Thus, the layer of first bearing material provides seizure resistance and compatibility with the shaft journal surface and prevents the journal surface from coming into contact with the strong backing material. As noted above, whilst the first bearing

material provides seizure resistance and compatibility, it is generally harder than the material of the second layer. Thus, it is inferior in terms of its ability to accommodate small misalignments between bearing surface and shaft journal (conformability) and in the ability to embed dirt particles circulating in the lubricating oil supply so as to prevent scoring or damage to the journal surface by the debris (dirt embedability).

10 The first bearing material may commonly be chosen from either aluminium alloy or copper alloy materials. Aluminium alloys generally comprise an aluminium or aluminium alloy matrix having a second phase of a soft metal therein. The soft metal phase may be chosen from 15 one or more of lead, tin and bismuth. However, lead is nowadays a non-preferred element due to its environmental disadvantages. Copper based alloys such as copper-lead and leaded bronzes are also likely to fall into disfavour eventually due to the environmental considerations and 20 may be replaced by copper-bismuth alloys, for example.

The second bearing material layer which co-operates with the shaft journal is also known as an overlay layer and has been generally formed by a relatively very soft metal 25 layer. An example is lead-tin alloy deposited, for example, by electrochemical deposition. Such alloys, however, in addition to being undesirable environmentally are also prone to wear in modern highly loaded engine applications. In order to replace such overlay alloys 30 with lead-free, more wear resistant alternatives much work has been carried out on soft aluminium alloys having relatively high tin contents and which are deposited by techniques such as a cathodic sputtering, for example. A disadvantage of such techniques is that such bearing 35 layers are expensive to produce, the process being an

essentially small batch process due to the vacuum sputtering equipment required.

In order to solve the problems electro-deposited lead-tin 5 alloys and later sputtering techniques, some workers have turned to polymer based overlays for oil lubricated, hydrodynamically loaded journal bearings.

JP-A-11106775 describes an overlay having a polymer 10 matrix of a polyamidoimide resin and having 20 to 69.7 vol% of a self lubricating phase therein. The examples show 28 to 63 vol% of the self lubricating phase (molybdenum disulphide). The self lubricating phase may be selected from molybdenum disulphide, graphite, 15 tungsten disulphide and the like.

JP-A-11106779 describes a similar material, the examples in this case containing from 30 to 70 vol% of molybdenum 20 disulphide, but where the resin matrix has a tensile strength in excess of 100Mpa.

However, a problem with such high contents of self lubricating materials of the types described is that whilst the frictional properties and the wear resistance 25 of the material may be adequate, the fatigue strength is frequently impaired.

The present invention has been made to overcome the disadvantages of the prior art.

30 According to a first aspect of the present invention there is provided a plain bearing having a sliding layer of a bearing material thereon, the bearing material comprising a polymer-based matrix selected from the group 35 comprising modified epoxy resin and polyimide/amide

resin, the matrix having contained therein at least one addition selected from the group comprising: metal powder in the range from 15 to 30 vol%; a fluoropolymer powder in the range from 1 to 15 vol%; ceramic powder in the 5 range from 0.5 to 20 vol%; and, silica in the range from 1 to 20 vol%.

Bearings according to the present invention are intended to operate in hydrodynamically loaded applications such 10 as internal combustion engine main and connecting rod bearings where the pattern of loading is extremely non-uniform, ranging from low load levels to very high peak loads within one complete engine cycle. Thus, bearing materials for such applications must possess not only 15 high strength per se, but also high fatigue strength to withstand the cyclic loading to which they are subjected and also very high levels of adhesive bond strength to the substrate on which the material is deposited.

20 In the applications intended, the temperatures experienced are generally higher than those to which plastics bearing materials are normally subjected. Moreover, the applications are oil lubricated thus, the plastics materials must be resistant to the hot chemical 25 additives employed in modern oils to maintain their lubricating qualities under the arduous conditions pertaining in modern high-performance engines.

30 In this specification the term "modified epoxy resin" is intended to cover a resin comprising from 30 to 60 w/w epoxy resin and 70 to 40 w/w phenolic resin based on solids to solids content. The phenolic component of the matrix resin provides good heat and chemical resistance whereas the epoxy component whilst also being very 35 chemically resistant also enhances flexibility of the

bearing material layer and promotes improved adhesion to the substrate on which it is deposited.

In the case of the polyimide/amide matrix resin, the 5 polyimide is a majority constituent. Polyimide resins have outstanding chemical resistance and also outstanding heat resistance, being able to withstand temperatures up about 400°C. Moreover the adhesive characteristics of polyimides to a substrate are also excellent.

10 The metal powder constituent is present due to the benefits conferred in terms of wear resistance in accommodating high bearing loads and also in improving the impact resistance ability of the bearing material in 15 view of high firing loads generated during the operation of internal combustion engines.

The metal powders may themselves comprise mixtures of different metal or metal alloy powders in preferred 20 proportions. In one embodiment of a bearing material according to the present invention, the metal powder may comprise a mixture of aluminium and tungsten metals in the proportion of 40/60% Al/W by volume. However, the relative proportions may range between 30/70 and 70/30 25 Al/W depending upon the actual engine bearing application in question.

The powder morphology of each constituent may vary. In the example described above, the W particles may 30 preferably be nodular or rounded, e.g. spherical, as this morphology for the very hard W particles lends itself to improving wear resistance due to a uniform distribution of these hard particles within the matrix.

The softer Al powder constituent on the other hand may be of flake or leaf-like morphology as this provides a greater surface area and which particles tend to align themselves generally with the plane of the bearing 5 material layer and so provide a high temperature lubricating effect in use. Alternatively, the Al constituent may also be of nodular particle morphology as this has also been found to be beneficial in some situations.

10

It is preferred that generally pure Al is employed as the thermal conductivity of this material is beneficial in conducting heat from the bearing into the housing in which it is held and also to the circulating lubricating 15 oil for bearing cooling purposes.

The range of total metal powder content may be from 15 to 30 vol%. Below 15vol% the improvement in wear resistance is insufficient whereas above 30 vol% the bearing 20 material becomes too hard and porosity tends to be produced in the layer which is detrimental to fatigue strength and adhesion of the material to the substrate.

Particle size of the metal powder constituent may lie in 25 the range from 0.5 to 10 μ m.

Alternative metal powder constituent combinations to Al/W described above may include Al/Sn; Ag/Cu; Cu/W. However, it will be appreciated by those skilled in the art that 30 other combinations may be employed, e.g. Ag/W and also that the individual powders may not necessarily be elements but may also be alloy particles such as stainless steel, brasses or bronzes, for example. Whilst lead or lead-containing materials are beneficial for

bearing properties, such materials are non-preferred owing to their environmental and safety disadvantages.

A fluoropolymer may be included in the bearing material 5 for its beneficial effect on material frictional properties and its self lubricating effect. A suitable material may be polytetrafluoroethylene (PTFE), however, other fluoropolymers may be used but the performance is inferior to PTFE.

10

A suitable range for fluoropolymer content may be from 1 to 15 vol% with 2 to 8 vol% being a preferred range. Too high a content of fluoropolymer reduces the matrix hardness and strength by an unacceptable degree.

15

Particle size of the fluoropolymer desirably lies in the range from 1 to 5 μ m. A size range of 2 to 3 μ m is preferred.

20

The term "ceramic" powder is used in a general sense to include additions of non-metallic, inorganic particulate materials which serve to improve the wear resistance and strength of the polymer matrix. Examples of such materials may include oxides, nitrides, carbides, 25 sulphides and the like. Tests have been conducted using alumina and glass beads as additions to the polymer matrix.

Content of ceramic powder may range from 0.5 to 20 vol%.

30

Above 20 vol% the material becomes too hard and inflexible whereas below 0.5 vol% the beneficial effects on wear and matrix strength are not fully realised. A content of 2 to 20 vol% is preferred.

Silica is distinguished from the ceramic powder additions discussed above as it is not added as a powder and has further, more far reaching effects on the polymer material and bearing as a whole than do the ceramic 5 powder additions above. Addition of silica may be made to the epoxy- based matrix material in the range from 2 to 15 vol%. Silica has the effect of strengthening the matrix and having a beneficial effect on wear resistance. Below 2 vol% the effects are not sufficiently realised 10 whereas above 15 vol% the matrix becomes too hard and inflexible. 4 to 10 vol% is a preferred range.

The type of silica is important as this has a significant effect on the bearing characteristics of the material. 15 Preferably, the particle size of silica should be in the range from 20 to 50 nanometres. The type of silica used actually assists the adhesion of the polymer layer to the substrate. The chemical form of silica used possesses "-OH" groups on the surface of the particles and which bond 20 to a metallic substrate surface and thus, improve both the strength and the fatigue resistance of the material by the improved bond strength. Thus, the silica used is not merely a free particle within a matrix but a "reactive" form of silica in which the -OH groups are 25 reactive and polar and which thus improves adhesion.

Desirably, the total content of solids additions to the plastics matrix should not exceed 30 vol% irrespective of the total individual constituent contents specified 30 above. In general, the total solids content of additions to the matrix may lie in the range from 10 to 30 vol%.

35 Preferably, the bearing material according to the present invention also includes a further addition of a separate adhesion promoting agent. Such adhesion promoting

materials may be based on silane materials and are effective by means of one end of the silane molecule bonding by cross linking with the polymer matrix and the other end of the molecule, which possesses a high proportion of "-OH" groups bonding with the metal substrate. An addition in the range of 0.2 to 3 vol% is preferred. Examples of suitable materials may include bis-(gamma-trimethoxysilylpropyl)amine and gamma-glycidoxypolytrimethoxysilane.

10

The bearing according to the present invention may comprise one of several different forms.

15

For example, the strong backing material may be steel and have deposited thereon a layer of a first bearing material, the first bearing material having deposited thereon a second, polymer-based, bearing material according to the present invention. In this instance the first bearing material may comprise a metallic bearing material based on an aluminium alloy or a copper alloy, for example.

20

In some circumstances the layer of the first bearing material may itself constitute the strong backing material per se. In this instance a tin-bronze material may be used, for example.

25

Where the polymer-based bearing material according to the present invention is deposited upon a layer of a first bearing material, then it may have a thickness in the range from about 5 to 40 μ m. a thickness range of 10 to 30 μ m is, however, preferred.

It is envisaged that the polymer-based bearing material of the present invention may be deposited directly upon a strong backing material which itself is not a bearing material in the recognised sense. An example of this would be a steel backing with a layer of

5 the polymer-based bearing material deposited thereon. In such a construction, the thickness of the polymer-based bearing material according to the present invention may be greater than where there is an intervening layer of first bearing material. In this construction, the thickness of the layer of polymer-based bearing

10 material may lie in the range from 40 to 100 μ m. A preferred range may be from 40 to 70 μ m.

The polymer-based bearing materials of the present invention may be applied as a liquid to the substrate. Moreover, the polymer-based materials may be thinned with appropriate solvents and sprayed by known techniques onto a desired substrate. Control of layer thickness is good and thicker layers may be formed by the spray deposition of a plurality of layers.

20 Where the method of deposition is by the spraying of a thinned layer or layers, the sprayed material may first be given a low temperature heat treatment to remove solvent followed by a further consecutive heat treatment to cure the polymer matrix.

25 In order that the present invention may be more fully understood, examples will now be described by way of illustration only.

Two different materials were made for testing based on the epoxy/phenolic material and on the polyimide/amide material.

The compositions of these materials are set out in Table 1 below.

Concentration by volume dry product.

5 Concentrations of materials by volume, in cured product, based on epoxy/phenolic and PI resin.

Table 1

Raw Materials	Particle shape	Approximate Particle size	Formulation Ref
Epoxy/Phenolic		01-008 S1	01-008 H1
Polyimide/polyamide		69.3	01-008 Y
Tungsten	Spherical	79.303	80.75
Aluminium	Spherical	6.58	4.5
Silica	Spherical	5 micron	18.09
Polytetrafluoroethylene	Spherical	50 nanometers	5.35
Aluminium	Irregular	1-3 micron	4.1
Ceramic beads	Spherical	5 microns	1.8
Aluminium oxide	Irregular	5 - 10 microns	6.1
Bis(gamma-trimethoxysilylpropyl)amine	1-3 micron	5.65	9.3
Polyester dimethylpolysiloxane		0.96	14.4
Processing parameters		0.96	14.4
Curing temperature		0.027	14.4
Curing time			0.05
Thickness on Copper alloys & Aluminium			
Thickness on steel			
Solvent content			
Solvent content m/L			
Raw Materials	Particle shape	Approximate Particle size	Formulation Ref

		01-008 327	01-008 326	01-008 C1	01-008 M1	01-008 R2
Epoxy/Phenolic						
Polyimide/polyamide		61.75	79.87	61.75	79.87	65.26
Tungsten	Spherical	5 micron	17.25	9.34	17.25	9.34
Aluminium	Spherical	5 micron	11.6		11.6	
Tin	Irregular	30 microns				10.4
Polytetrafluoroethylene	Spherical	1-3 micron	7.7	4.24	7.7	4.24
Aluminium	Irregular	5 microns	6.3		6.3	
Ceramic beads	Spherical	5 – 10 microns				
Aluminium oxide	Irregular	1-3 micron				6.0
Silica	Irregular	10-13nm.				1.09
Stainless Steel	Lamellar	Approx 5 microns				9.3
Bis(gamma-trimethoxysilylpropyl)amine						
Polyester dimethylpolysiloxane		1.7	0.19	1.7	0.19	0.55
Processing parameters						
Curing temperature		190oC	185oC	190oC	185oC	190oC
Curing time		30 min	20 min	30 min	20 min	30
Thickness on Copper alloys & Aluminium		15 μ m	15 μ m	15 μ m	15 μ m	15 μ
Thickness on steel		50 – 100 μ m	50 - 100 μ m			
Solvent content		Approx 870	Approx 760	Approx 870	Approx 760	Approx 760
Solvent content mL						

The concentrations of additions to the matrix are by volume% in the cured material based on the density of the particular matrix polymer in each case.

5 Reference in "processing parameters" to copper alloys and
aluminium alloys refers to the substrate material on which
the polymer is deposited. The substrate in all cases is
further provided with a strong backing material of steel.

10 Bearings were formed from coated substrates and tested for
wear in a known "Viper" wear test rig and for fatigue
strength in a known "Sapphire" fatigue test rig. Test
conditions for each type of test are given below.

15 Viper wear tests are accelerated wear tests and have
conditions:

Load	8kgs
Shaft roughness	0.2 Ra
Shaft speed	500 rev/min
Oil temperature	120°C
Test duration	10 mins to 360 mins.

The bearings were weighed before and after each test and the weight loss taken to represent resistance to wear. The weight losses were converted into volume losses to permit accurate comparisons of wear behaviour.

Sapphire fatigue tests were conducted on half bearing samples comprising a steel backed, cast copper-lead alloy bearing metal lining and having an overlay coating according to the present invention sprayed in the bore thereof. Test rig temperature was 80°C; running periods of 20 hrs at each load were used with load increments of 7kgs at each time period.

Results of the tests are given below in Table 2.

Table 2

5

Material	Coating Thickness	PVC	Substrate	Wear Volume loss mm ³	Time minutes	Fatigue strength MPa	Time Hours
Modified Epoxy Al/W H1	25µm	30%	VP2	0.122	60	76	100
Polyimide Al/W 327	12µm	30%	VP2	0.505.	60	103	180
Polyimide Al/W 326	18µm	30%	VP2	0.501	60	83	120
Polyimide Al/W C1	10µm	30%	VP2	0.463	60	90	140
Polyimide Al/W C1	25µm	30%	VP2	0.463	60	90	140
Polyimide Al/W M1	15µm	20%	F90	0.122	60	76	100
Polyimide Al/w Y	15µm	15%	VP2	0.122	60	103	180
Polyimide Al/W/Ceramic K1	15µm	20%	F90	0.027	60	83	120
Polyimide Al/W/Ceramic L1	15µm	20%	F90	0.022	60	76	100
Polyimide Al/W/Alumina S1	15µm	20%	VP2	0.24	60	76	100
Polyimide Al/Stainless steel/Alumina R2	15µm	20%	VP2	0.00	60	97	160

Table 3 below gives comparative data on known metallic overlays and shows Viper (wear volume loss) and Sapphire (fatigue strength) results on known metallic electro-deposited overlay materials.

5

Table 3

Material	Coating Thickness	Substrate	Wear Volume loss mm ³	Time Mins	Fatigue strength MPa	Time hrs
Pb-10Sn-2Cu	12μm	VP2	7.8	12	69	80
Pb-In	12μm	VP2	10.2	12	76	100
Pb-10Sn-1 Alumina	12μm	VP2	0.5	60	83	120

10 The polymer overlay compositions were all sprayed onto a range of copper-based (VP2) and aluminium-based (F90) bearing alloys.

15 The column headed "PVC" denotes the total "pigment volume content" in the matrix and comprises metal powder, silica, fluoropolymer and all other additions in the final, as-cured and tested bearing material.

20 It may be seen that the wear and fatigue resistance of polymer based overlays according to the present invention are in most cases superior to metallic overlays as set out in Table 3. Only the composite overlay comprising a co-electrodeposited alumina phase (Pb-10Sn-1alumina) in the overlay matrix has wear and fatigue resistance approaching that of the polymer overlays according to the present invention. However, the prior art metallic overlays are costly to produce, especially the alumina containing composite material and are also environmentally undesirable being based on a lead matrix. Overlay according to the 30 present invention may be made up in bulk and applied with

relative ease by known and well understood and controllable spraying processes.

CLAIMS

1. A plain bearing having a sliding layer of a bearing material thereon, the bearing material comprising a polymer-based matrix selected from the group comprising modified epoxy resin and polyimide/amide resin, the matrix having contained therein at least one addition selected from the group comprising: metal powder in the range from 15 to 30 vol%; a fluoropolymer powder in the range from 1 to 15 vol%; ceramic powder in the range from 0.5 to 20 vol%; and, silica in the range from 2 to 15 vol%.
- 10 2. A plain bearing according to claim 1 wherein the modified epoxy resin comprises from 30 to 60 w/w epoxy resin and 70 to 40 w/w phenolic resin based on solids to solids content.
- 15 3. A plain bearing according to claim 1 wherein polyimide is a majority constituent in the polyimide/amide matrix resin.
- 20 4. A plain bearing according to any one of preceding claims 1 to 3 wherein the metal powder comprises mixtures of different metal powders in preferred proportions.
- 25 5. A plain bearing according to claim 4 wherein the metal powder comprises a mixture of aluminium and tungsten metals in the range between 30/70 and 70/30 Al/W volume%.
- 30 6. A plain bearing according to claim 5 wherein the proportions of Al and W powders are 40/60% Al/W by volume.
7. A plain bearing according to either claim 5 or claim 6 wherein the morphology of the W particles is nodular or rounded.

8. A plain bearing according to any one of preceding claims 5 to 7 wherein the Al powder is of flake or leaf-like morphology.
9. A plain bearing according to any one preceding claim 5 wherein the particle size of the metal powder constituent lies in the range from 0.5 to 10 μ m.
10. A plain bearing according to any one preceding claim from 1 to 4 wherein the metal powder constituent is selected from the group comprising: Al/Sn; Ag/Cu; Cu/W; Ag/W.
11. A plain bearing as claimed in any one preceding claim from 1 to 4 wherein the metal powders comprise metal alloy particles.
12. A plain bearing according to claim 11 wherein the 15 alloys are selected from the group comprising: stainless steel, aluminium alloys, brasses and bronzes.
13. A plain bearing according to any one preceding claim wherein the fluoropolymer is polytetrafluoroethylene.
- 20 14. A plain bearing according to any one preceding claim wherein the fluoropolymer content lies in the range from 1 to 15 vol%.
15. A plain bearing according to claim 14 wherein the fluoropolymer content lies in the range from 2 to 8 25 vol%.
16. A plain bearing according to any one preceding claim wherein the ceramic powder is selected from the group comprising: oxides, nitrides, carbides and sulphides.
17. A plain bearing according to any one preceding claim 30 wherein the ceramic content lies in the range from 2 to 20 vol%.
18. A plain bearing according to any one preceding claim wherein the silica content lies in the range from 4 to 10 vol%.

19. A plain bearing according to any one preceding claim wherein the particle size lies in the range from 20 to 50 nanometres.
20. A plain bearing according to any one preceding claim wherein the silica is reactive silica and possesses "-OH" groups on the particle surface.
21. A plain bearing according to any one preceding claim wherein the total addition of solids content to the polymer matrix does not exceed 30 vol%.
- 10 22. A plain bearing according to claim 21 wherein the total solids content of additions to the matrix may lie in the range from 10 to 30 vol%.
23. A plain bearing according to any one preceding claim further including a silane material in the range of 15 0.2 to 3 vol%.
24. A plain bearing according to claim 23 wherein the silane material is selected from the group comprising: bis-(gamma-trimethoxysilylpropyl)amine and gamma-glycidoxypyltrimethoxysilane.
- 20 25. A plain bearing according to any one preceding claim wherein the polymer based bearing material is deposited upon a layer of another bearing material.
26. A plain bearing according to claim 25 wherein the other bearing material is selected from an aluminium 25 alloy or a copper alloy.
27. A plain bearing according to either claim 25 or claim 26 wherein a thickness of the polymer based bearing material lies in the range from 5 to 40 μ m.
28. A plain bearing according to any one preceding claim 30 from 1 to 24 wherein the polymer based bearing material is deposited directly upon a strong backing material.

29. A plain bearing according to claim 28 wherein a thickness of the polymer based bearing material lies in the range from 40 to 100 μ m.
30. A plain bearing according to any one preceding claim wherein the polymer based bearing material is applied as a liquid to the substrate.
5
31. A plain bearing according to claim 30 wherein the liquid is sprayed.
32. A plain bearing substantially as hereinbefore described with reference to the accompanying description and any one of the examples described in Table 1.
10

33. ABSTRACT

A plain bearing having a sliding layer of a bearing
5 material thereon is described, the bearing material
comprising a polymer-based matrix selected from the group
comprising modified epoxy resin and polyimide/amide resin,
the matrix having contained therein at least one addition
selected from the group comprising: metal powder in the
10 range from 15 to 30 vol%; a fluoropolymer powder in the
range from 1 to 15 vol%; ceramic powder in the range from
0.5 to 20 vol%; and, silica in the range from 2 to 15 vol%.

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